APPENDIX 3I EVALUATION FOR HIGH FREQUENCY SEISMIC INPUT

3I.1 Introduction

The seismic analysis and design of the AP1000 plant is based on the Certified Seismic Design Response Spectra (CSDRS) shown in subsection 3.7.1.1. These spectra are based on Regulatory Guide 1.60 with an increase in the 25 hertz region. Ground Motion Response Spectra (GMRS) for some Central and Eastern United States rock sites show higher amplitude at high frequency than the CSDRS. Evaluations are described in this appendix for the seismic input at the Bellefonte site where the nuclear island is founded on hard rock. Figure 3I.1-1 and Figure 3I.1-2 compares the GMRS (based on Bellefonte input) at the foundation level against the AP1000 CSDRS for both the horizontal and vertical directions for 5% damping. The Bellefonte GMRS exceed the CSDRS for frequencies above about 15 Hz.

High frequency seismic input is generally considered to be non-damaging as described in Reference I.1. The evaluation of the AP1000 nuclear island for the high frequency input is based on the analysis of a limited sample of structures, components, supports, and piping to demonstrate that the high frequency seismic response is non-damaging. The evaluation includes building structures, reactor pressure vessel and internals, primary component supports, primary loop nozzles, piping, and equipment.

This appendix describes the methodology and criteria used in the evaluation to confirm that the high frequency input is not damaging to equipment and structures qualified by analysis for the AP1000 CSDRS. It provides supplemental criteria for selection and testing of equipment whose function might be sensitive to high frequency. The results of the high frequency evaluation demonstrating that the AP1000 plant is qualified for this type of input are documented in a technical report (Reference I.2). This report will provide a summary of the analysis and test results.

3I.2 High Frequency Seismic Input

Presented in Figures 3.I-1 and 3.I-2 is a comparison of the horizontal and vertical GMRS from the Bellefonte site and the AP1000 CSDSR. The Bellefonte GMRS presented is calculated at foundation level (39.5' below grade), at the upper most competent material and treated as an outcrop for calculation purposes.

For each direction, the Bellefonte GMRS exceeds the design spectra in higher frequencies (greater than 15 Hz horizontal and 20 Hz vertical). The spectra are used for the GMRS. If necessary, the Bellefonte GMRS spectra are enhanced at low frequencies so that GMRS fully envelopes all of the hard rock sites.

3I.3 NI Models Used To Develop High Frequency Response

The NI20 nuclear island model described in Appendix 3G is analyzed in SASSI using the Bellefonte time histories applied at foundation level to obtain the motion at the base. To assure that the high frequency content at the base is transferred up the nuclear island structures and equipment, the base motion is applied to the NI10 ANSYS model described in Appendix 3G. The analyses are performed using the foundation motion and the NI10 surface mounted model since side soil effects are considered to be small because of the small deformation associated with the high frequency response on hard rock. These analyses are performed for incoherent motion using the coherency function described in Reference I.3.

The fixed base NI10 ANSYS nuclear island model defined in Appendix 3G is analyzed using the basemat response from the NI20 incoherent analyses as input The NI10 model has greater refinement than the NI20 model and is therefore better suited for the high frequency building response.

3I.4 Evaluation Methodology

The demonstration that the AP1000 nuclear power plant is qualified for the high frequency seismic response does not require the analysis of the total plant. The evaluations made are of representative systems, structures, and components, selected by screening, as potentially sensitive to high frequency input in locations where there were exceedances in the high frequency region. Acceptability of this sample is considered sufficient to demonstrate that the AP1000 is qualified.

The high frequency seismic analyses that are performed use time history or broadened response spectra. The analysis is not performed using the envelope spectra of the CSDRS and the GMRS. Separate analyses with each spectra are used.

The evaluations performed assess the ability of the system, structure, or component to maintain its safety function.

Supplementary analyses are performed as needed to show that high frequency floor response spectra exceedances are not damaging. These analyses can include: gap nonlinearities; material inelastic behavior; multi point response spectra analyses where the high frequency response excites a local part of the system. Tests on equipment are specified as needed where function cannot be demonstrated by analysis, or analysis is not appropriate.

3I.5 General Selection Screening Criteria

The following general screening criteria are used to identify representative AP1000 systems, structures, and components (SSCs) for the samples to be evaluated to demonstrate acceptability of the AP1000 nuclear power plant for the high frequency motion.

- Select systems, structures, and components based on their importance to safety. This includes the review of component safety function for the SSE event and its potential failure modes due to an SSE. Those components whose failure modes would result in safe shutdown are excluded.

- Select systems, structures, and components that are located in areas of the plant that experience large high frequency seismic response.

- Select systems, structures, and components that have significant modal response within the region of high frequency amplification. Significance is defined by such items as : modal mass; participation factor, stress and/or deflection.

- Select systems, structures, and components that have significant stress as compared to allowable when considering load combinations that include seismic.

3I.6 Evaluation

In this section the portions of structures, the components, and the systems that are evaluated for the high frequency seismic response are identified. The sample to be evaluated, based on the screening criteria applicable to the SSCs consists of the following:

- Building Structures
  - Auxiliary Building – 3 locations
  - Shield Building – 8 locations
  - CIS – 2 locations
- Primary Coolant Loop
  - Reactor Vessel and Internals
  - Primary Component Supports
  - Reactor Coolant Loop Primary Equipment Nozzles
- Piping Systems – at least two piping analysis packages
- Electro-Mechanical Equipment – Equipment that is potentially sensitive to high frequency input (see Table 3I.6-1)

These structures, systems, and equipment are discussed in more detail in the sections that follow.

3I.6.1 Building Structures

Maintaining the NI buildings structural integrity is important to the safety of the plant. Representative portions of the buildings that are evaluated for the effect of high frequency input are selected based on those areas that can experience high seismic shear and moment loads due to the seismic event. Areas chosen are at the base of the shield building, in the vicinity of auxiliary building floors that have fundamental frequencies in the high frequency region, and the corners of the auxiliary building. Three locations are selected on the auxiliary building that reflect the bottom of a wall where the shear and moment would be large, a wall in the vicinity of a floor that is influenced by high frequency response, and a corner intersection of walls. Eight locations are evaluated on the shield building. Four at elevation 107' and four at elevation 211'. These locations are located on the east, west, north and south sides. The south-west wall of the refueling canal is evaluated since it is a representative wall on the refueling canal. The CA02 wall in the CIS building is evaluated since it is a representative wall associated with the IRWST.

The evaluation consists of a comparison of the loads from the high frequency input to those obtained from the AP1000 design spectra, shown in Figures 3I.1-1 and 3I.1-2, for these representative building structures. The NI building structures are considered qualified for the high frequency input if the seismic loads from the Regulatory Guide 1.60 (modified) envelope those from the high frequency input. If there is any exceedance, this is evaluated further to confirm that the existing design is adequate.

3I.6.2 Primary Coolant Loop

A failure within the reactor coolant loop could challenge the integrity of the reactor coolant pressure boundary. Therefore, it is chosen for evaluation. The components evaluated are as follows:

- Reactor vessel and internals
- Reactor vessel supports
- Steam generator supports
- Reactor coolant loop primary equipment nozzles

The reactor vessel and internals are selected since they are important to safety and their analysis is representative of major primary components. The building structure below the reactor vessel supports is fairly stiff and there may be significant vertical amplification at the supports of the reactor pressure vessel. Further, reactor vessel internals have relatively complex structural systems including gap nonlinearities and sliding elements. Also, they may be sensitive to high frequency input as summarized below:

- Vertical and horizontal modes of the upper internals and the reactor vessel modes are in the relatively high frequency range.

- Additional high frequencies are associated with nonlinear impact

The evaluation consists of a comparison of the loads from the high frequency input to those obtained from the Regulatory Guide 1.60 (modified) input. Qualification is shown for the high frequency input if the seismic loads from the Regulatory Guide 1.60 (modified) envelope those from the high frequency input. If there is exceedance, then comparison is made for the combination of the seismic with the design basis pipe break loads and steady state loads. Qualification is then shown if the high frequency loads are relatively insignificant compared to the other loads, or there are no required design changes.

Maintaining the integrity of the reactor vessel and steam generator supports is important to preserving the primary component safety function. They are representative of supports on components, and see high loads.

The reactor coolant loop nozzles at the cold and hot leg interfaces of the reactor pressure vessel, reactor coolant pumps, and steam generators are important to include in the evaluation since these are critical areas of components.

The evaluation of the primary component supports and reactor coolant loop nozzles consists of a comparison of the loads from the high frequency input to those obtained from the Regulatory Guide 1.60 (modified) input. These items are considered qualified for the high frequency input if the seismic loads from the Regulatory Guide 1.60 (modified) envelope those from the high frequency input. If there is any exceedance, then an evaluation is made combining the high frequency loads with the other load components (e.g., thermal, pressure, dead) and a comparison made to the design loads. If the design loads envelope the load combinations that include the high frequency seismic input, then the nozzles and supports are considered qualified for the high frequency input.

3I.6.3 Piping Systems

Safety class piping analysis packages were reviewed and include a mixture of ASME Class 1, 2, and 3 piping systems. They typically contain at least one valve. The piping systems are mainly large bore of various size (3-inch diameter to 38-inch diameter), and some of small bore (2 inches and lower). The piping systems are in both the containment and auxiliary building.

The piping systems chosen for evaluation are those that are susceptible to high frequency as measured by their mass participation in the higher frequencies, are representative piping systems that contain valves and equipment nozzles, and are located in areas susceptible to high frequency Bellefonte GMRS spectra level response. At least two candidate piping analysis packages are identified for evaluation that meet these screening criteria.

The pipe stresses, nozzle loads, and valve end loads obtained from both the high frequency input and the Regulatory Guide 1.60 (modified) input are compared. Comparison is also made to the allowables with the seismic stresses combined with the other stresses associated with the seismic load combination that is applicable as necessary. If the high frequency seismic results are below those associated with the Regulatory Guide 1.60 (modified) results, or below the allowable limits, then the piping system is considered qualified. If necessary, more detailed supplementary analyses will be performed considering one or more of the following:

- Multi-point response spectra input
- Non-linear analysis with gap and material nonlinearities
- Calculation of actual support stiffness in locations where a minimum rigid value was used

3I.6.4 Electro-Mechanical Equipment Qualification

The groups of safety-related equipment considered for evaluation are those that may be sensitive to the high frequency input. This includes cabinet mounted equipment, field sensors and appurtenants which may be sensitive to high frequency seismic inputs identified in Table 3I.6-1.

Sample safety-related cabinets have been identified that are typically sensitive to seismic input. Evaluations will be performed to verify these cabinets do not have excessive seismic demand on their mounted equipment, the cabinet designs do not require changes due to the high frequency input, and the cabinets will maintain their structural integrity during the high frequency input. Time history analyses of these cabinets are performed for both the Regulatory Guide 1.60 (modified) and the high frequency inputs so that comparisons can be made to their seismic response from both seismic inputs. This analytical study is to conclude that safety-related equipment may be screened and grouped as follows:

Screening Process

Group No. 1:

Rugged equipment with high frequency content above 60 Hz. This group will require no additional evaluation for high frequency seismic inputs.

Group No. 2:

Cabinets and other equipment which exhibit most of their effective mass (80% and higher) with modes below 15 Hz. This group will require no additional evaluation for high frequency seismic inputs.

Group No. 3:

Cabinet and other equipment which exhibit dominant natural frequencies between 15 Hz and 60 Hz. This group is classified into three sub-groups as follows.

A. Tune the mounting configurations of the cabinet to reduce its dominant natural frequencies below 15 Hz (equal to group No. 2. This subgroup will require no additional evaluation for high frequency seismic inputs.)

B. Tune the mounting configurations of the cabinet to shift dominant natural frequencies higher than 60 Hz (mainly in the vertical direction) (equal to group No. 1. This subgroup will require no additional evaluation for high frequency seismic inputs.)

C. This group will have dominant natural frequencies in the range of 20 to 60 Hz and can't be shifted out of this range. This group is the only group required high-frequency evaluations. It can be evaluated as follows:

   1. If cabinet and equipment structures have been seismically tested and qualified to low frequency input higher than the high-frequency seismic requirements or with a ZPA (at 33 Hz) higher than the spectral acceleration of the high-frequency input, then no additional testing or analysis are required.

   2. If not, then structure can be shown qualified by analysis and sensitive components by testing to high frequency excitation.

Qualification Process

In the high frequency screening process, the potential failure modes of high frequency sensitive component types and assemblies are important considerations. The following are potential failure modes of high frequency sensitive components/equipment.

- Inadvertent change of state
- Chatter
- Change in accuracy and drift in output signal or set-point
- Electrical connection failure or intermediacy (e.g., poor quality solder joints)

- Mechanical connection failure
- Mechanical misalignment/binding (e.g., latches, plungers)
- Fatigue failure (e.g., solder joints, ceramics, self-taping screws, spot welds)
- Improperly and unrestrained mounted components
- Inadequately secured/locked mechanical fasteners and connections

Components and equipment determined to be exposed to and are high frequency sensitive with potential failure modes involve change of state, chatter, signal change/drift and connection problems shall be demonstrated to be acceptable through the performance of supplemental high frequency qualification testing. Those high frequency sensitive component having failure modes associated with mounting, connections and fasteners, joints, and interface are considered to be qualified by traditional low frequency qualification testing per IEEE Std 344 and/or required quality assurance inspection and process/design controls.

High frequency seismic testing for sensitive equipment will be conducted as a supplemental test to low frequency seismic excitation. High and low frequency seismic required response spectra (RRS) are separate environments and an envelope RRS covering both would not be representative of the design basis event (DBE). Testing to a High/Low Frequency Envelope RRS could prove destructive to both the equipment under test and the seismic test table.

When high frequency seismic testing is performed following a low frequency seismic testing, the equipment shall be subjected to the high frequency SSE testing after completion of the low frequency seismic testing. Low level cycling fatigue effects requirement shall be justified represented by low frequency seismic input. No additional low level testing for high frequency excitation is required. One SSE high frequency seismic test will be performed to demonstrate functionality of equipment in its most sensitive electrical configuration.

Acceptance and qualification to the high frequency input is determined based on the comparison of the test levels the components have been analyzed or tested to. For those equipment/components determined to have already been tested to high seismic levels in the high frequency region, no additional testing or justifications will be necessary. A review of seismic testing data is performed to verify that the tested seismic levels envelop the high frequency seismic demand. If these components cannot be shown to be acceptable based on this review, additional testing or justifications may be required to show qualification.

3I.7 References

1. EPRI Draft White Paper, “Considerations for NPP Equipment and Structures Subjected to Response Levels Caused by High Frequency Ground Motions,” Transmitted to NRC March 19, 2007.

2. APP-GW-GLR-115, “Effect of High Frequency Seismic Content on SSCs,” Westinghouse Electric Company LLC.

3. Personal correspondence related to approved incoherence function, Abramson – April 2007.

Table 3I.6-1

POTENTIAL SENSITIVE EQUIPMENT LIST

- Equipment or components with moving parts and required to perform a switching function during the seismic event (e.g., circuit breakers, contactors, auxiliary switches, molded case circuit breakers, motor control center starters, and pneumatic control assemblies)
- Components with moving parts that may bounce or chatter such as relays and actuation devices (e.g., shunt trips)
- Unrestrained components
- Potentiometers
- Process switches and sensors (e.g., pressure/differential pressure, temperature, level, limit/position, and flow)
- Components with accuracy requirements that may drift due to seismic loading
- Interfaces such as secondary contacts
  - Connectors and connections (including circuit board connections for digital and analog equipment)

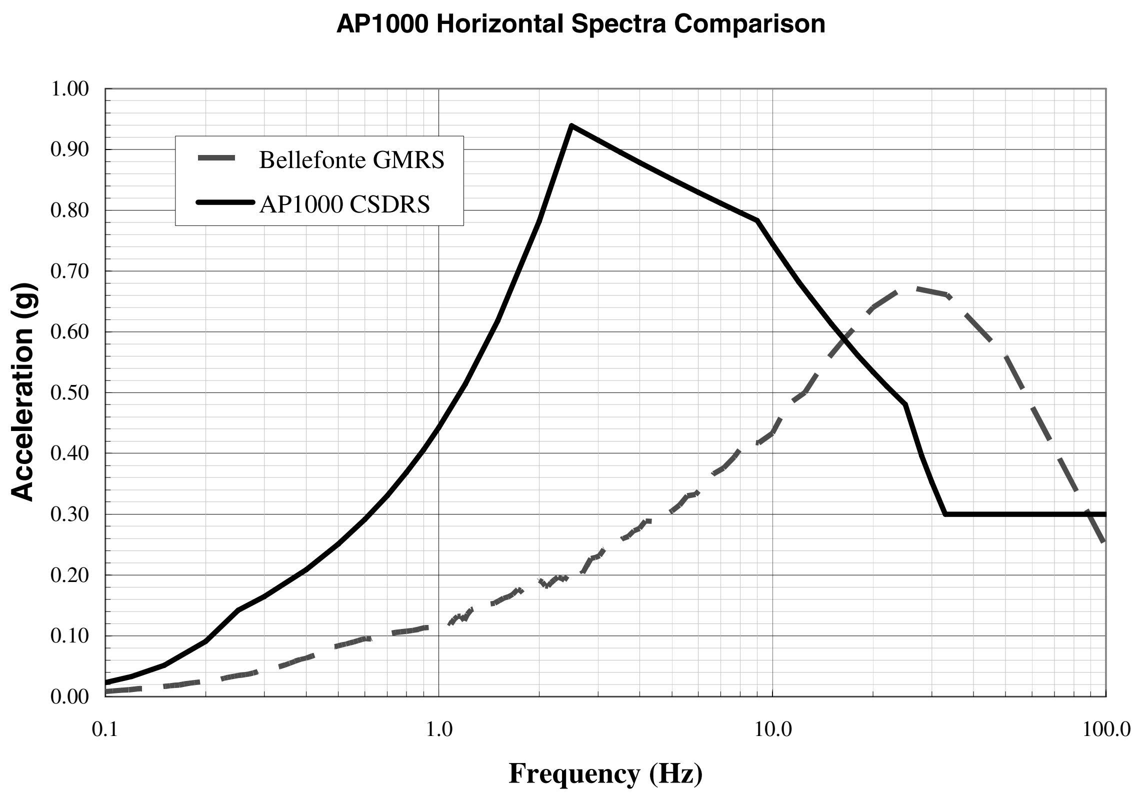

Figure 3I.1-1

Comparison of Horizontal AP1000 CSDRS and Bellefonte GMRS

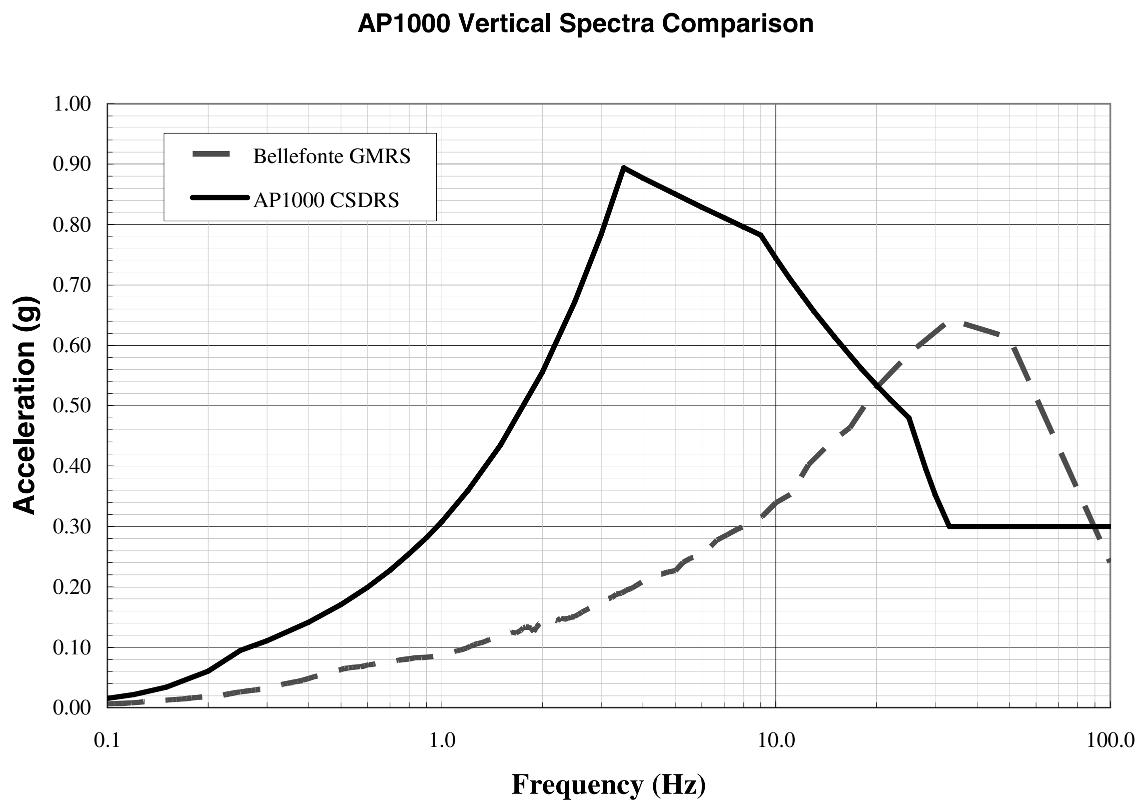

Figure 3I.1-2

Comparison of Vertical AP1000 CSDRS and Bellefonte GMRS